Modelling of declining groundwater depth in Kurukshetra district, Haryana, India

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Changing climate of a region coupled with spatio-temporal variability of rainfall has a significant effect on groundwater recharge. An effort has been made in this study to analyse the pre- and post-monsoon average groundwater depths of different blocks in Kurukshetra district, Haryana, India. The stochastic analysis of groundwater depth was carried out using auto regressive integrated moving average (ARIMA) model. Best-fitted models ARIMA (2, 1, 1) and ARIMA (0, 1, 2) were used for prediction of pre- and post-monsoon groundwater depth fluctuations up to the year 2020. Results indicate that by the year 2020, average groundwater depth in the pre- and post-monsoon seasons in the district is expected to decline by 5.63 and 5.72 m respectively, over the base year 2010. Results of this study will be helpful in evolving strategies for groundwater development and management.

Keywords: Climatic variability, groundwater depth, irrigation, monsoon rainfall.

GROUNDWATER is a major source of freshwater in India. The share of groundwater in the net irrigated area is 61%, and about 60% of the irrigated food production depends on groundwater for irrigation in the country[1,2]. Besides fulfilling the irrigation needs, groundwater provides for more than 80% of the rural, and 50% of the urban and industrial requirements in India[3]. Productivity of groundwater-irrigated areas is more than canal-irrigated areas by one-third to one-half because it offers greater control over water supply[3,4]. However, during the last four decades, uncontrolled withdrawal of groundwater for irrigation in parts of arid and semi-arid regions in India has seriously depleted the aquifers. At the same time, over-exploitation of groundwater in many blocks of the country has resulted in decline of water levels and reduction in well yield[5,6]. Statistics shows that during the last four decades, groundwater wells and tube wells have increased many fold, mainly in arid and semi-arid regions of the country[6]. In many blocks of Haryana, India, the stage of groundwater development is more than 100%, which indicates that groundwater withdrawal is more than its recharge per year[6]. Studies on climate change have revealed its significant impact on groundwater recharge. Climatic variability may alter the rate and amount of rainfall, its spatio-temporal distribution, rate of evaporation and transpiration which may affect the rate of groundwater recharge and future availability[7–10]. Thus the combined effect of climate change and increased demand of groundwater may further lower the water table depth. Rice and wheat cropping system is dominant in Kurukshetra district, Haryana, where about 82% of the area is irrigated through groundwater. The groundwater development stage in Kurukshetra district is 166%. Analysis of groundwater table depth for 24 years showed a declining trend in the district at a rate varying from 0.98 to 1.16 m/yr (ref. 11). This has threatened the sustainability of irrigated agriculture in the district.

Mathematical (quantitative) forecasting models are useful in detecting the past and future trend in long-term time series of hydro-meteorological parameters. Knowledge of future trend helps in the efficient planning and appropriate use of groundwater resources in a region. Time-series models detect the past trend in time-series data and help forecast the future trend on the basis of underlying patterns contained within the data series. Generally, parametric and non-parametric methods are used for identifying the trend in the time-series analysis of hydro-meteorological parameters[12,13]. Stochastic analysis of long-term time-series data of groundwater depths is available in the literature[14–16]. Non-parametric methods were also used for detection of trends and change in magnitude of slope per unit time of groundwater levels[17–19]. Time-series model, namely auto regressive integrated moving average (ARIMA) model is popular and is used by researchers for the analysis of hydro-meteorological parameters and groundwater depth for forecasting the future trend for these parameters[20–24]. The knowledge of past studies shows that time-series models are useful for trend detection and forecasting of groundwater depth in the future. Accurate groundwater depth forecasts are important for estimating potential hazards associated with groundwater depth changes in advance, to help farmers and other people cope with the problems. Keeping this in view, the present study was undertaken to evaluate the trend in the pre- and post-monsoon water levels and forecast the future behaviour of groundwater depth of Kurukshestra district.

The study area is bounded by 29°53′00″–30°15′02″N lat., and 76°26′27″–77°07′57″E long., and spread over 1530 km^2. The district consists of five blocks, namely Ladwa, Pehowa, Shahabad, Thanesar and Babain (Figure 1). It has 1510 km^2 of total cultivable area, of which 1500 km^2 is irrigated. Area irrigated by canal and tube wells is 270 and 1230 km^2 respectively. The share of groundwater-irrigated area in the total irrigated area is 82%. Irrigation intensity in the district is about 180%. The district falls under semi-arid region and experiences hot summers and cold winters. It receives about 81% of its normal annual rainfall (582 mm) during the months of

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Figure 1. Location of the study area.

July to September. Topographically, the study area is a plain surface having an average elevation varying from 274 to 241 m amsl. The district consists of three types of soil, namely sandy loam, loam and clay loam having low to moderate permeability.

Block-wise groundwater depth data (1974–2010) for pre- and post-monsoon seasons were collected from the Groundwater Cell under the Department of Agriculture, Haryana, and were used for the analysis. A block is a spatial unit within the district considered for all developmental activities and reporting of groundwater data. In this study, average groundwater depths of pre- and post-monsoon time-series of Kurukshetra district were analysed and predicted using the ARIMA model[25].

The ARIMA model is written as ARIMA (p, d, q), in which p, d and q are integers. In ARIMA (p, d, q), p explicates the auto-regressive (AR) part, d the integrated part (I) and q the moving average (MA) part[25]. The AR part indicates the lasting effect of previous scores, the I part indicates trends in the data, and the MA part shows the lasting effects of previous random scores. The basic assumption for successful ARIMA model fitting is that the data series is stationary. This means that data series varies around a constant mean and variance. If the data series is non-stationary, it needs differencing. The model development involves three steps, namely identification, estimation and diagnosis. The initial step is identification, which is accomplished by the examination of autocorrelation functions (ACFs) and partial autocorrelation functions (PACFs) of time-series data to find the specific pattern in the data. In case, time series is non-stationary, transformation is required to make it stationary; this is done through differencing the scores of time series once or twice and examining the behaviour of ACF and PACF. The next step involves selection of a temporary model which is accomplished by comparing ACF and PACF of the stationary time series of data. ACF and PACF helps to decide the suitable range of initial model parameters of a time series and subsequently model parameters are estimated. Among the identified models, ARIMA model having lesser value of the Bayesian information criterion (BIC) is considered as more prudent. Diagnosis is the third step of the model development process. This is completed by examination of the residual scores which are helpful to find any unaccounted patterns in the data series. If the model is adequate, the estimated ACF of the residual is independent and normally distributed. The Ljung–Box–Pierce statistics is used to test the adequacy of the model. The analysis was carried out using the SPSS 17.0 software. Time series of groundwater depth was partitioned into 70 : 30 ratios. First series of 26 years' data (1974–1999) was used for parameterization and development of the ARIMA model, and the second series of 11 years' groundwater depth data (2000–2010) was used for model validation.

The values of p and q were fixed on the basis of plots of ACF and PACF of pre- and post-monsoon groundwater depth time-series data for each block and the entire district. Analysis was carried out separately for pre- and post-monsoon groundwater depths. Figure 2 shows sample plots of ACF and PACF for pre-monsoon average groundwater depth of the district. In ACF plot, four spikes cutting the confidence level indicate the serial dependence and correlation in original time series. In case of PACF, a single spike at lag one cuts the upper confidence limit. This also shows strong serial dependence, thus making the time series non-stationary. This serial dependence and correlation was removed by

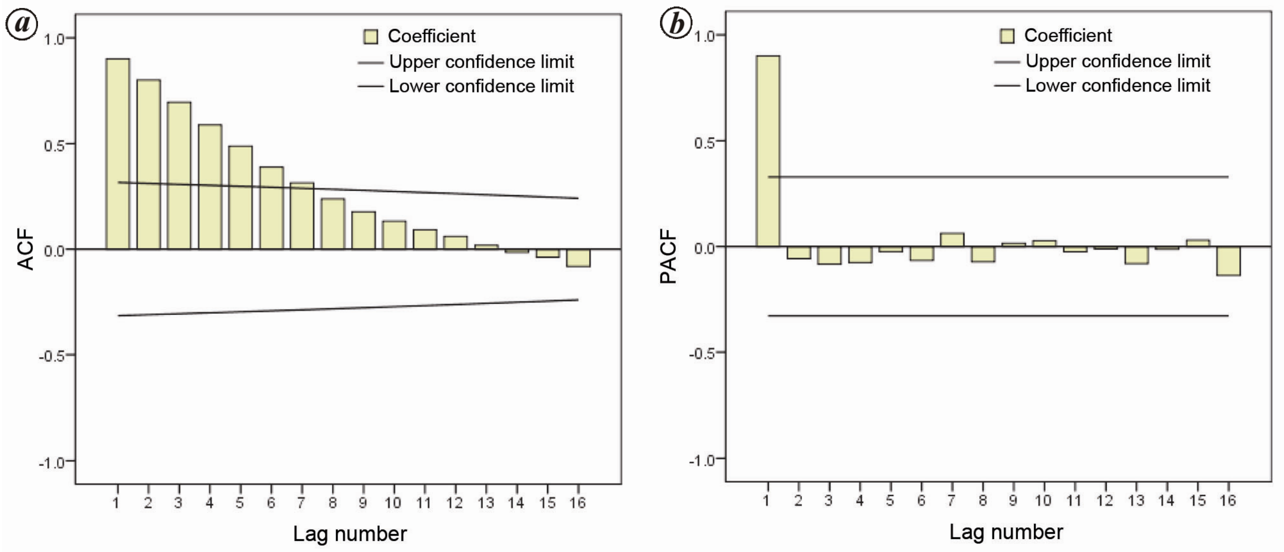

Figure 2. Autocorrelation function (ACF) (***a***) and partial autocorrelation function (PACF) (***b***) of pre-monsoon water depths without differencing.

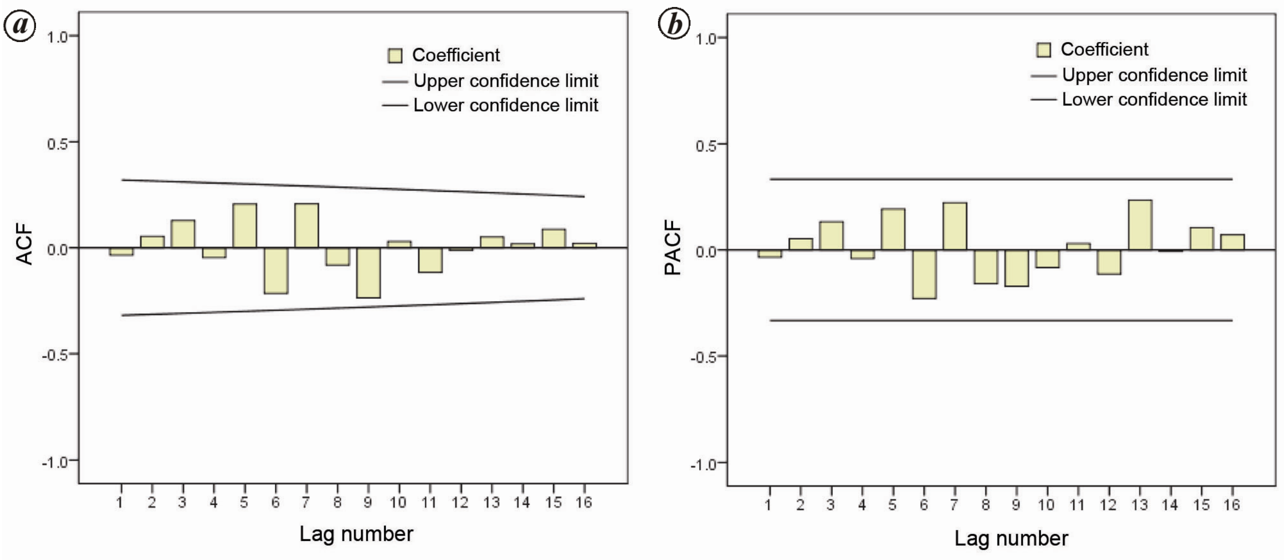

Figure 3. ACF (***a***) and PACF (***b***) of pre-monsoon water depths with differencing.

Table 1. Diagnostic analysis of selected models based on Bayesian information criterion (BIC)

	Pre-monsoon		Post-monsoon
ARIMA model	BIC	ARIMA model	BIC
110	0.50	012	0.73
011	0.51	110	0.80
211	0.61	011	0.85
112	0.63	112	0.86

differentiating the time series once and making it stationary. Figure 3 shows plots of ACF and PACF after differentiating of pre-monsoon groundwater depths. A similar procedure was adopted for the time series of post-monsoon average groundwater depths of the district. Tentative ARIMA models (values of p, d and q) were identified from the knowledge of ACF and PACF. Several models were built up by trial and error method within reasonable limits. Among those developed, four models were selected using minimum BIC for further diagnostic analysis (Table 1).

For improving model predictability of all the four chosen ARIMA models, plots of the residuals of ACF and PACF were examined. The plots of all four models were critically checked for any systematic pattern contained within the time series of residuals for pre- and post-monsoon average groundwater depths of Kurukshetra

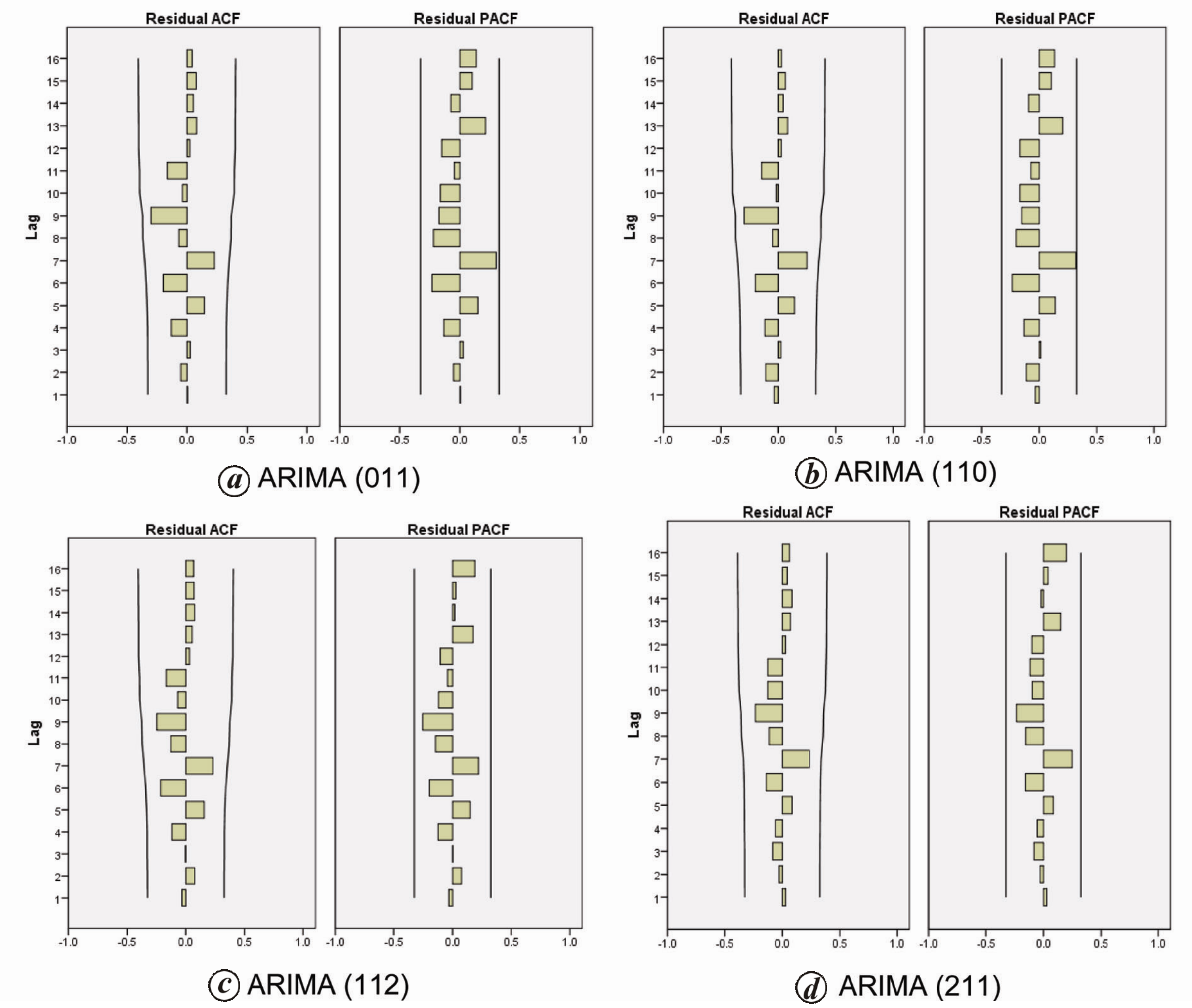

Figure 4 *a–d*. ACF and PACF of residuals of pre-monsoon groundwater depths.

Table 2. Model parameters of pre- and post-monsoon groundwater depths

ARIMA model	RMSE	MAPE	MAE	Statistics
Pre-monsoon groundwater depths				
110	1.16	6.67	0.93	14.29
011	1.17	6.76	0.95	14.52
211	1.11	6.33	0.89	11.64
112	1.12	6.52	0.92	14.51
Post-monsoon groundwater depths				
012	1.24	7.83	1.00	10.98
110	1.35	8.01	1.06	17.77
011	1.38	8.28	1.09	19.48
112	1.26	7.87	1.00	11.29

RMSE, Root mean square error; MAPE, Mean absolute percentage error; MAE, Maximum absolute error.

district. The estimated residual scores of pre- and post-monsoon groundwater depths for the four selected ARIMA models were plotted in terms of ACF and PACF of residuals (Figures 4 and 5 respectively). The results show that the residuals are within confidence limit. A close examination of these plots shows the marginal difference for the four selected models, which corroborates that these models have been appropriately selected.

Ljung Box Q statistics of the four identified models was compared for both pre- and post-monsoon groundwater depths respectively, for model verification. ARIMA model having the lowest Q value was verified and selected as the most appropriate model. The other performance parameters of the selected models were also considered, viz. root mean square error (RMSE), mean absolute percentage error (MAPE), and maximum absolute error (MAE). Lowest values of these parameters were adjudged for selection of the best-fitted model (Table 2). Model ARIMA (2, 1, 1) and ARIMA (0, 1, 2) were recognized as best-fitted among four selected models for pre-monsoon and post-monsoon average groundwater depths in Kurukshetra district.

The best-fitted models ARIMA (2, 1, 1) and ARIMA (0, 1, 2) were again validated by comparing the predicted and observed pre- and post-monsoon average groundwater depths in Kurukshetra district for the period from

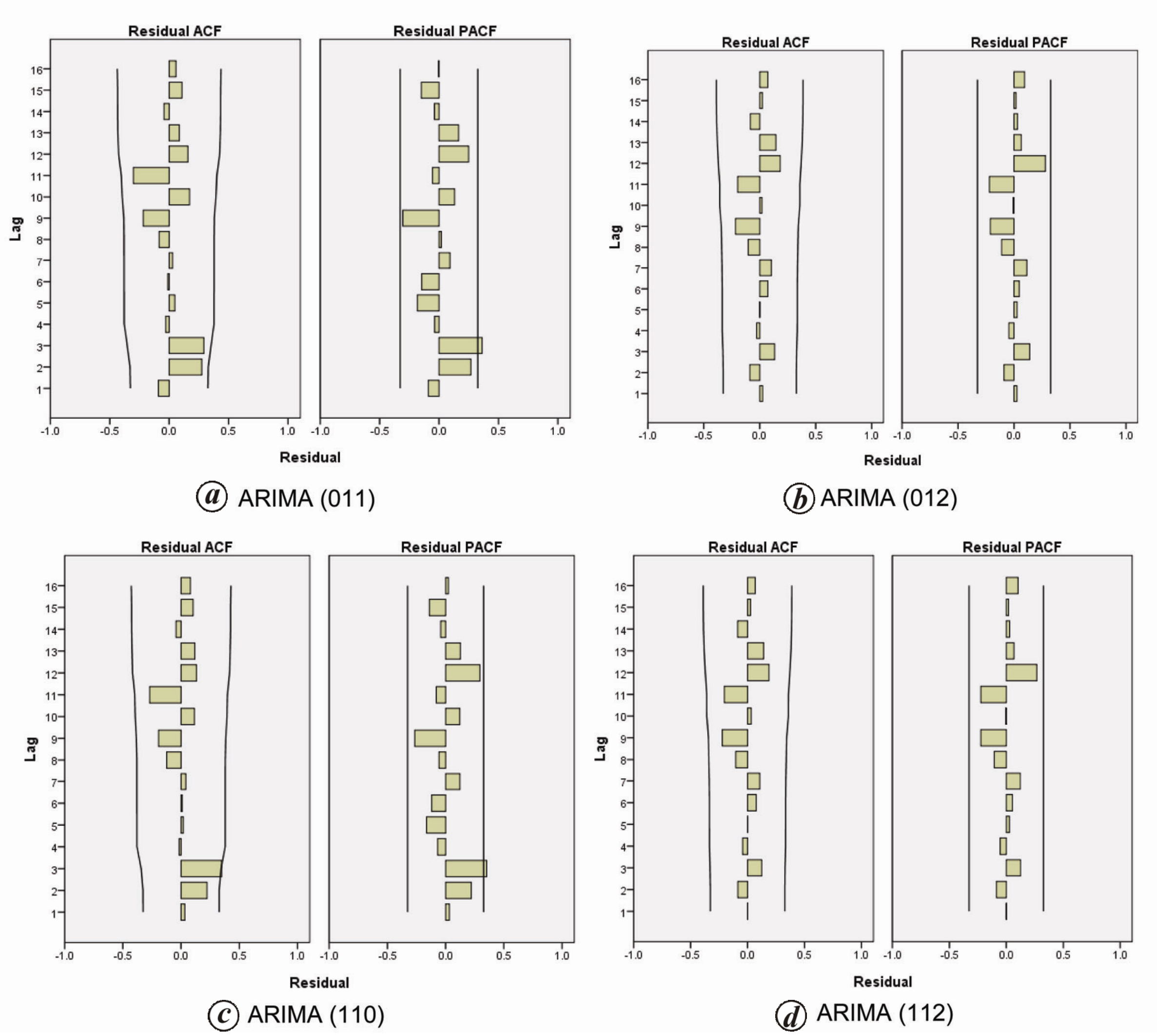

Figure 5 *a–d*. ACF and PACF of residuals of post-monsoon groundwater depths.

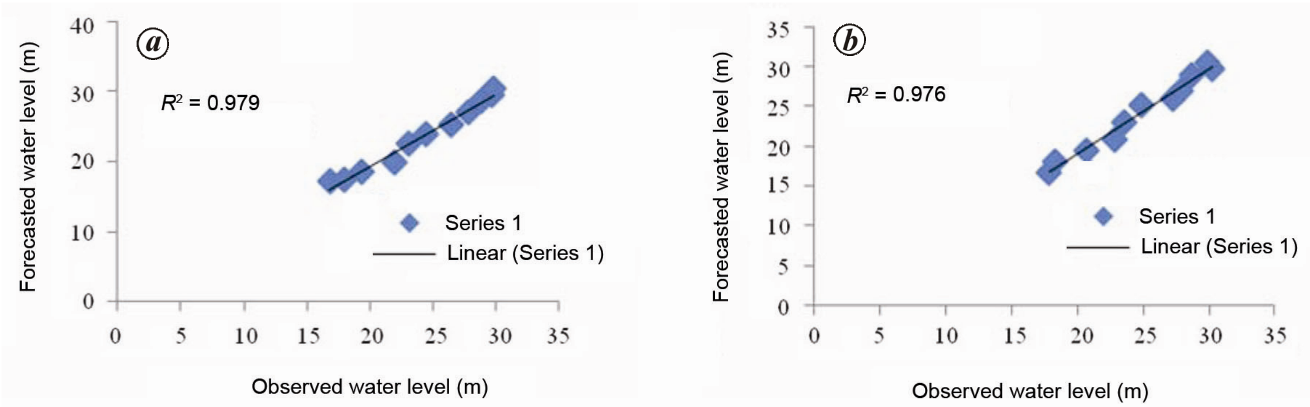

Figure 6. Comparison of observed and predicted pre-monsoon (***a***) and post-monsoon (***b***) groundwater depths.

2000 to 2010. Table 3 shows the results of model validation. Results show that RMSE, MAPE and MAE are within the acceptable range. Figure 6 *a* and *b* shows plots of observed and predicted average pre- and post-monsoon groundwater depths respectively. Results indicate higher predictability of both the models, namely ARIMA (2, 1, 1) and ARIMA (0, 1, 2) for pre- and post-monsoon groundwater depths with R^2 values of 0.867 and 0.865 respectively. Hence ARIMA (2, 1, 1) and ARIMA (0, 1, 2) were chosen for accurate prediction of average groundwater depths in the entire district. Similar procedure was adopted for selecting the best-fitted models for other

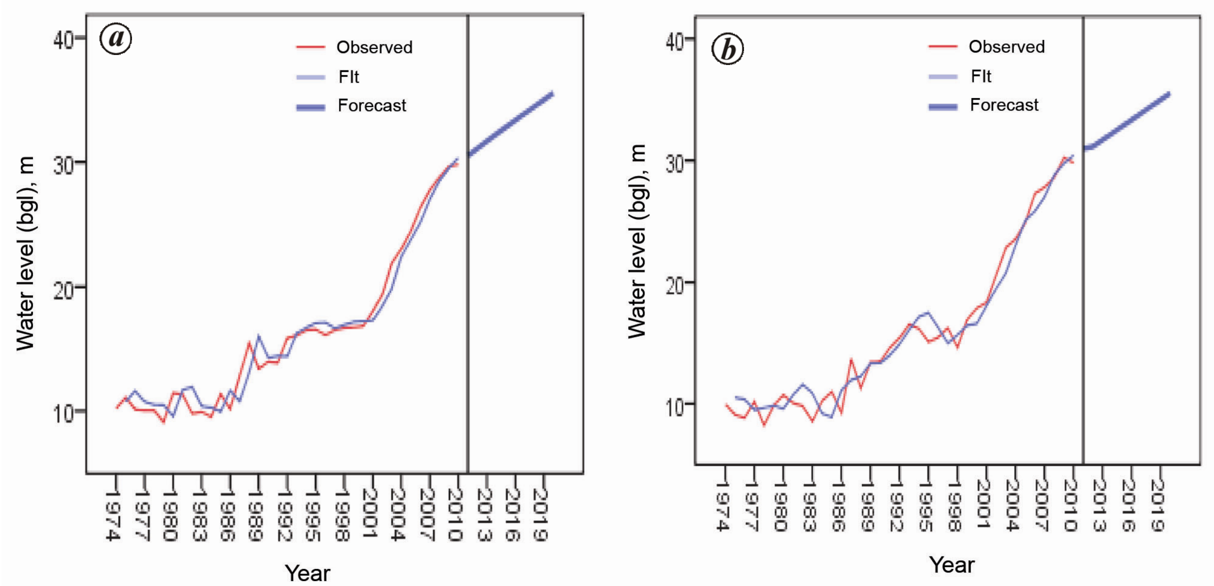

Figure 7. Predicted pre-monsoon (***a***) and post-monsoon (***b***) groundwater depths for 2020.

Table 3. Model parameters for validation

	RMSE	MAPE	MAE
Pre-monsoon groundwater depths			
ARIMA (2 1 1)	0.752	1.685	0.423
Post-monsoon groundwater depths			
ARIMA (0 1 2)	0.902	2.546	0.622

Table 4. Block-wise best-fitted models of pre- and post-monsoon groundwater depths

	ARIMA model	
Block	Pre-monsoon	Post-monsoon
Ladwa	210	011
Pehwa	011	011
Shahabad	110	012
Thaneswar	210	012

blocks in the district. Table 4 presents the block-wise best-fitted models for Kurukshetra district.

Best-fitted models ARIMA (2, 1, 1) and ARIMA (0, 1, 2) were used for prediction of future pre- and post-monsoon average groundwater depths for the year 2020. Figure 7 shows the predicted average groundwater depths for Kurukshetra district. The results show that both pre- and post-monsoon groundwater depths in the district are expected to lower by 5.63 and 5.72 m below the ground surface by 2020 compared to those in 2010, if groundwater abstraction rate remains the same over the period.

Groundwater in agriculturally dominant Kurukshetra district of Haryana is over-exploited, which has been corroborated from the declining trends in groundwater depths during the period 1974–2010. The groundwater development stage in all five blocks is more than 100% and has been put under 'over-exploited' category. Stochastic analysis of groundwater depths carried out using best-fitted models ARIMA (2, 1, 1) and ARIMA (0, 1, 2) indicates that by the year 2020, average groundwater depths in the pre- and post-monsoon seasons in the district are expected to decline by 5.63 and 5.72 m respectively, over the base year 2010, if the groundwater abstraction continues at the same rate. The reason for such a decline can be attributed to the poor on-farm irrigation efficiency and partly to the intensive cropping system. Rice–wheat is a predominant cropping system practised in the district. In the past farmers had advanced the transplanting of rice much before the start of monsoon. High evapotranspiration during the hot summers led to an increase in irrigation. As mentioned earlier, the major source of irrigation in the district is groundwater (about 82% of irrigated area depends on groundwater). Similar analysis can be done for the entire state of Haryana, which would assist stakeholders in deciding management alternatives to arrest the decline of water table in the district.

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DB IndAlgae: an on-line resource of marine algae from India identified on the basis of molecular and morphological features

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DbIndAlgae is a free on-line database of marine algae from India. It provides information about the geographical distribution, morphological characteristics and most importantly, sequence data of marine algae collected from different coasts. It is the only database which contains molecular data of the algal species from India. Identification of the species is based on both morphological as well as molecular information. The database also serves as an interface to the herbarium maintained at the Centre for Plant Sciences, Central University of Punjab, Bathinda. So far the database lists 45 marine algal species. Some algal species have been identified for the first time from India, but have already been reported from places other than India, whereas new species are those which have been identified by us for the first time as a part of this study and have never been reported elsewhere.

Keywords: Database, marine algae, molecular and morphological features, *Ulva paschima*.

IDENTIFICATION, naming and cataloguing of different species of plants and animals form the basis for many conservation efforts such as Statutes and Acts, evolutionary studies, as well as commercial exploration. In India, the database DB IndAlgae (http://bit.ly/db-ia) is the first step in identifying and cataloguing marine algae. DB IndAlgae is an effort by us at the Marine Phycology Laboratory, Central University of Punjab, Bathinda. No previous attempts have been made in this regard to make information available on-line for easy access and effective dissemination. The data available at DB IndAlgae are the result of our ongoing research at the above-mentioned laboratory. The algal species listed in our database have been identified using both morphological as well as molecular features. Earlier plant taxonomists used only morphological features to distinguish different species but in some phyla where phenotypic plasticity occurs frequently, such as algae, mere morphology-based study can cause ambiguities, including misidentification of a taxon. The advancement in molecular phylogenetics and DNA barcoding has played a major role in remedying ambiguities in algal phylogeny[1]. Marine algal taxonomy used in this communication and in DB IndAlgae is according to AlgaeBase[2].

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